SUMMARY REPORT

1. INTRODUCTION

This study assesses the relative merits of spectrum around 800 Megahertz (MHz) as an operating frequency band for public safety land mobile communications, and the extent to which 800 MHz systems have affected interoperability among public safety entities at all levels of government. The intent is to determine the impact of the 800 MHz band on intra- and inter-jurisdictional interoperability at the local, state, and federal levels.

There are some 300 channels within the 800 MHz band available for use by state and local public safety entities. Of these channels, 230 channels became available in the mid-1980's and are managed under a process set out by the National Public Safety Planning Advisory Committee (NPSPAC). In the fielding of new systems, many state and local public safety entities are using these so-called NPSPAC channels, together with other 800 MHz channels. The Federal Communications Commission (FCC) has allocated spectrum in the 800 MHz band to public safety because frequencies in this band were made available, not necessarily because it is the optimal frequency band for public safety communications.

Neither the FCC, nor any other body has conducted studies to establish the appropriateness or efficacy of the 800 MHz band for public safety radio operations. In addition, the costs and operational changes associated with 800 MHz systems have not been systematically assessed. Given the latest allocation of additional 800 MHz spectrum for public safety use, a deliberate assessment of 800 MHz is in order. Such an assessment has been performed and is documented in this study. This study provides an opportunity to understand the relative benefits and shortcomings of spectrum around 800 MHz as an operational frequency band for public safety purposes.

1.1 Scope

This report is considered a "first-brush" examination of spectrum around 800 MHz as an operating frequency band for public safety use. The report provides the findings of Booz·Allen and Hamilton's analysis of the 800 MHz band. It includes an examination of the allocation, assignment, and administrative procedures for 800 MHz spectrum. Additionally, the report contains high-level technical characteristics of the 800 MHz band including technical comparisons of 800 MHz, Very High Frequency (VHF), and low-band Ultra High Frequency (UHF) signal propagation effects, as well as a summary of questions and answers asked of several public safety officials.

1.2 Approach

Booz·Allen & Hamilton followed a three-phased approach in performing this study: data collection, analysis, and study reporting. This approach is illustrated in Figure 1-1 and described in the following paragraphs.

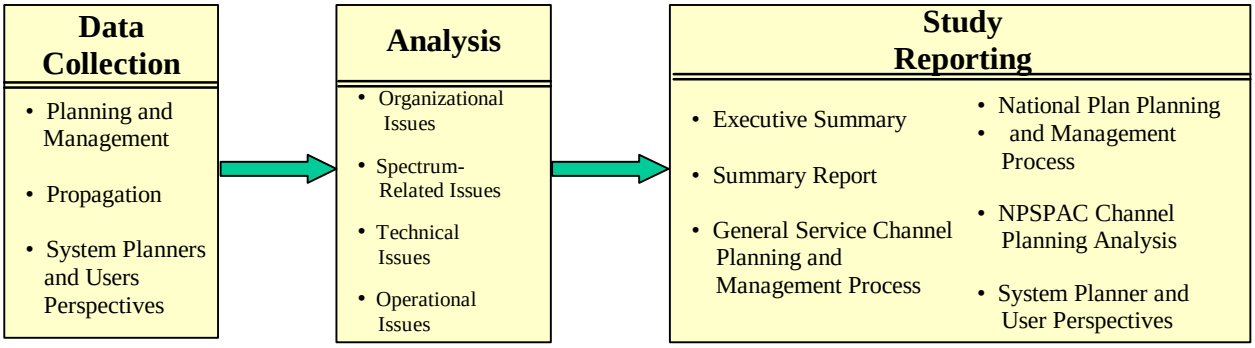

Figure 1-1
800 MHz Study Methodology

Data Collection…

In the data collection phase of the project, research efforts were organized into the following three subject areas based upon preliminary findings:

- **Planning and Management of 800 MHz Public Safety Frequencies.** The focus of this effort centered on FCC documentation (e.g., Notices of Inquiry, Public Notices, Notices of Proposed Rule Making, Reports and Orders [R&O], etc.) pertaining to the allocation and assignment of public safety spectrum at 800 MHz. Two planning and management processes for 800 MHz spectrum were studied: the process governing public safety's use of the general service channels (806-821/851-866 MHz band) and the process governing the NPSPAC channels (821-824/866-869 MHz band). Another critical component of the collected data was the 55 regional plans, and comments to these plans, outlining assignment and use of the NPSPAC frequencies. These plans were carefully analyzed and compared to one another for consistency, effectiveness, and overall utility.

- **Propagation Effects of 800 MHz.** Many concerns have been raised with respect to the propagation characteristics of radio signals at 800 MHz. Reports of dead spots and other common coverage problems are sometimes made by those operating, using, and considering new 800 MHz systems. In an effort to clarify these issues, an assessment of propagation effects at 800 MHz and at other public safety bands was included as part of this study. This assessment was performed by surveying the appropriate technical literature and applying the key principles from electromagnetic wave propagation theory to verify or refute common misconceptions of 800 MHz and other public safety bands.

- **System Planner and User Perspectives of 800 MHz Systems.** This effort was designed to provide system planners and users an opportunity to share their planning, implementation, and operational perspectives on all aspects of 800 MHz systems. A comprehensive interview guide was developed to collect information on these issues. The guide was used to conduct a series of face-to-face and telephone interviews with radio

managers, system administrators and regional planning committee chairmen. Insight was obtained into pressing issues such as:

- The drivers in the decision to move to 800 MHz or to remain in another frequency band
- The effects on operations and system costs
- The effects on interoperability among systems at all levels of government
- The extent that 800 MHz systems are installed as trunked systems
- The satisfaction with, and suggested changes to, policies, procedures, and technical standards that govern public safety spectrum.

Analysis…

To begin the data analysis phase, the overall findings of each of the aforementioned research efforts were assessed. In reviewing these findings, it was determined that the collected information could be organized into four areas of general interest:

- **Organizational Issues.** Several of the findings relate to how organizations responsible for the management and administration of the designated 800 MHz frequencies, such as the FCC and regional planning committees, performed their responsibilities. Of particular interest is the extent to which these organizations, and the procedures and processes they established and managed, enhanced or hindered the use of these 800 MHz frequencies by public safety entities.

- **Spectrum-Related Issues.** Some of the information uncovered by this study pertains to key characteristics of spectrum as a limited natural resource, whether around 800 MHz or any other public safety band. Issues addressed include the availability of spectrum, and a comparison of propagation effects at different bands.

- **Technical Issues.** Many findings of the study relate to technical characteristics of 800 MHz systems. These new 800 MHz systems are technically state of the art and offer their users a range of service and performance attributes that older, antiquated systems were simply unable to provide. Additionally this issue includes a discussion on schemes that make more efficient use of spectrum, and how these schemes are employed at 800 MHz.

- **Operational Issues.** Several of the findings relate to how 800 MHz systems have affected public safety operations. Among the points addressed are such issues as the need to better educate users about how the new system works, and how 800 MHz systems have altered day-to-day operations and how 800 MHz systems have improved or hindered inter-agency interoperability.

The findings of each area of study (i.e., planning and management, propagation, and system planner and user perspectives) are organized into the four issues of general interest identified above. Figure 1-2 illustrates the extent to which each area of study yielded findings in each of the issues of general interest. For example, the findings from the system planner and

user perspectives study area span each issue of general interest, but provides the greatest insight into operational issues associated with 800 MHz systems.

Figure 1-2
800 MHz Study Framework

Study Reporting…

The final phase of the 800 MHz Study was study reporting, which includes the organization of all collected data into key findings. The study is organized into six parts. The first is an up-front report summarizing the key findings of the study. The key findings are organized by the previously defined general issues (organizational, spectrum-related, technical, operational). Following the summary report are a series of appendices (A-E) that present detailed findings related to specific areas of the study. The data contained within each appendix is used to develop the findings contained within the summary report. A brief description of each appendix follows:

- *Appendix A* provides detailed analysis of the regulations and requirements of the general service channel (806-821/851-866 MHz) planning processes.

- *Appendix B* provides detailed analysis of the regulations and requirements of the National Planning process for the NPSPAC (821-824/866-869 MHz) frequencies.

- *Appendix C* provides analysis of the regional planning processes that were employed during the NPSPAC channel planning process.

- *Appendix D* is a collection of system planner and user reflections on many aspects of the 800 MHz band as a public safety operating band. This appendix also contains the results of the propagation area of study. This information is captured in the form of text boxes and is used to confirm or refute system planner and user realities and myths.

- *Appendix E* contains a list of commonly used abbreviations and acronyms.

The relationship between appendices and the summary report is shown in Figure 1-3.

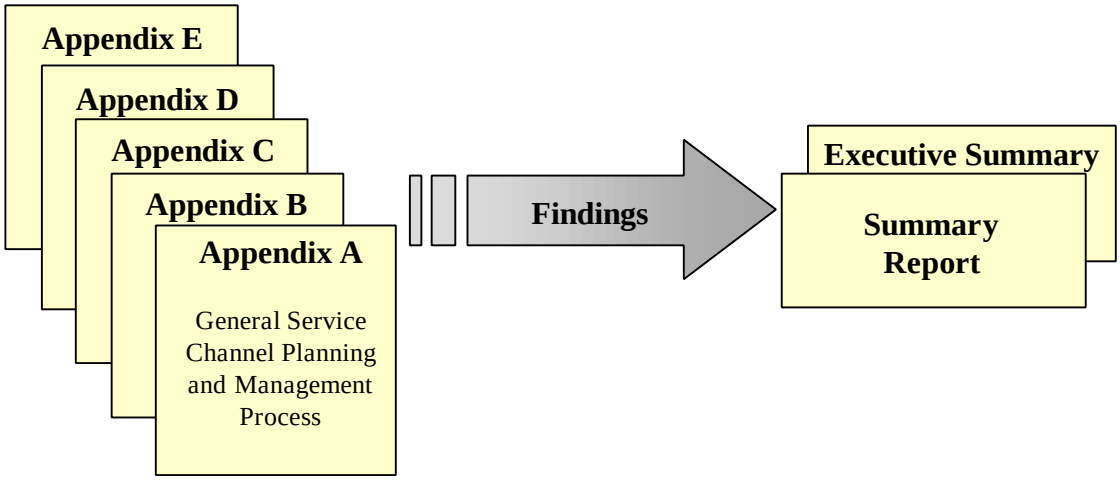

Figure 1-3
Document Organization

2. KEY FINDINGS

The analysis of 800 MHz systems for public safety based on the examination scheme described above yielded several key findings. These findings are organized and provided under each of the four issue areas (organizational, spectrum-related, technical, operational) as defined in the analysis phase of the approach.

Organizational Issues

General Service Channel Process . . .

- In the 1970s, the FCC allocated the general service channels in the 806-821/851-866 MHz band for public safety use. To assign and regulate these channels, the FCC adopted a flexible regulatory philosophy that allowed system planners a great deal of freedom to implement new 800 MHz systems.

- The flexible nature of the general service channel planning and management process led to the proliferation of a variety of incompatible systems. In the absence of any common standards or regulating guidelines, vendors, independent of one another, developed systems that lacked a common interface to allow interoperable communications.

- Despite the involvement of the public safety community at the onset of this process, no official procedure was developed for coordination among separate public safety entities during the frequency assignment and systems development phases of the process.

NPSPAC Channel Process . . .

- In the 1980s, the FCC allocated channels in the 821-824/866-869 MHz band for public safety use. These channels would become known as the "NPSPAC channels" because the regulations and policies governing the use of these channels were based on the recommendations of the NPSPAC.

- The inability of public safety radio communications to support, enable, and improve coordination efforts among multiple agencies was highlighted during response efforts to the Washington, D.C. Air Florida crash and the D.C. Metrorail derailment in 1982. Communications problems encountered during these response efforts included the lack of interoperability among agencies, overcrowded radio channels, and the lack of available spectrum for use by the public safety community. In response to these problems, the FCC, through the efforts of the NPSPAC, developed the National Plan.

- The National Plan led to the regional planning process that empowered state and local public safety entities to plan frequency assignments for systems within their regions.

  – This process lasted over five years, during which time most regional planning committees were inactive.

  – Success in achieving the primary goals (promoting spectral efficiency and improving interoperability) set forth in the National Plan was limited.

- The National Plan mandates that membership on the regional planning committees be open to representatives from all eligible user groups, including both governmental and non-governmental users. Under the Plan, the responsibility to determine eligibility was left to each regional committee. Although broad participation was desired, oversight activities to ensure robust committee membership were not performed.

  – Large portions of committee memberships consist of law enforcement agencies from large metropolitan areas.

  – Fire departments, emergency medical service (EMS) organizations, and emergency medical technicians (EMT) are underrepresented.

  – Small public safety entities consisting of less than 25 members lack representation in the regional planning committees.

  – Because of the voluntary nature of the regional planning process, many small public safety entities are unable to effectively participate in the regional planning committees.

- Federal public safety agencies operating in the regions were not involved in the planning sessions, therefore, opportunities for exploring shared system development between local, state, and federal agencies were missed.

- Lack of participation was driven, in part, by the high costs of travelling to meetings across the region and the administrative costs voluntarily absorbed by members of the regional committee.

- The majority of regional planning committees used a standardized regional plan developed by the Association of Public-Safety Communications Officials International, Inc. (APCO) as a template for creating their regional plans.

  - The use of a standardized regional plan may have stifled the creativity of the planning committees in developing their individual regional plans.

  - The use of a standardized plan to expedite the regional planning process is indicative of the lack of significance that some regional committees placed on the planning process associated with the NPSPAC channels.

- Several regional planning committees submitted regional plans to secure the NPSPAC channels regardless of their actual intent to use these channels.

- Some regional planning committees had token coordination with adjacent regions while developing their regional plans.

  - Ineffective coordination between regional planning committees led to the development of several unresolved inter-regional disputes

  - Ineffective coordination between regional planning committees contributed to the increasing problems of inter-jurisdictional interoperability.

- The National Plan created mutual aid channels to be used to facilitate interoperability among local, state, and federal public safety agencies.

  - The NPSPAC mutual aid channels are conventional mode channels. These conventional channels offer means of communication between incompatible trunked mode systems and provide spectrum for interoperability among public safety entities.

Spectrum-Related Issues

- Public safety radio systems serving areas of high population density (e.g., metropolitan areas) remain overcrowded and overloaded. There are two available means of relieving these deficiencies: 1) obtaining additional frequencies, and 2) using available spectrum more efficiently.

- Some system users associate increased capacity with the implementation of an 800 MHz system. In actuality, these systems are experiencing increased capacity due to the implementation of trunking technology or the availability of additional channels.

- Shortages of 800 MHz frequencies were identified in some metropolitan areas and at international borders. The allocation of additional spectrum for public safety in the 700 MHz band (764-776/794-806 MHz) should help relieve congestion in some of these areas.

- The majority of 800 MHz users have "given back" some previous operating frequencies to the FCC but retain the rest for continued radio communications use.

The propagation characteristics of public safety operating frequency bands were included in the study analysis. This analysis included a high-level comparison of physical propagation characteristics of public safety frequency bands and an assessment of these frequency bands with regard to specific propagation characteristics. Figure 1-4 illustrates the findings of this comparative analysis.

- The losses associated with certain signal propagation characteristics do not become significant until well into the GHz range.[1]

  - Losses due to terrain or forestation are less at lower frequency bands than at the higher frequency bands. The losses associated with terrain and forestation are insignificant for frequencies below 1 GHz.

  - However, at 800 MHz, higher losses have been noted for coniferous forests. This reported effect may be due to pine needles being of a similar size to quarterwave whip antennas, thus scattering radio signals and causing signal fading.

  - Even though signal fading is more pronounced at 800 MHz than at VHF, this propagation characteristic does not noticeably affect the performance of systems operating below 3 GHz.

- Some systems planners are choosing to build new systems in the lower frequency bands, despite the availability of 800 MHz spectrum. Some of the deciding factors are as follows:

  - An inverse relationship exists between frequency and range — as frequency increases, range decreases

[1] An empirical relationship for foliage loss is $L=1.33f^{0.284}d^{0.588}$, where L is foliage loss in decibels along a path blocked by dense, dry, in-leaf temperate-climate trees, *f* is the frequency in gigahertz, and *d* is the path length in meters. (See Hess, Garry C. Land-Mobile Radio System Engineering. Boston: Artech House, 1993: pp. 24.)

DEGREE OF EFFECT (Greater ↓ Less)	Common Propagation Concerns				
	Range (Note 1)	**Building Penetration** (Note 2)	**Terrain Loss** (Note 3)	**Foliage Loss** (Note 4)	**Signal Fading** (Note 5)
Greater	Low-Band VHF	Low-Band VHF	800 MHz	800 MHz	800 MHz
	High-Band VHF	High-Band VHF	Low-Band UHF	Low-Band UHF	Low-Band UHF
	Low-Band UHF	Low-Band UHF	High-Band VHF	High-Band VHF	High-Band VHF
Less	800 MHz	800 MHz	Low-Band VHF	Low-Band VHF	Low-Band VHF

Notes: (1) In some cases, propagation losses at 800 MHz are twice as great as the losses experienced at VHF frequencies.[2]

(2) The higher the frequency, the greater the reflective properties of the signal. Low frequency (VHF and below) signals will experience little reflection and will tend to penetrate large structures such as buildings.[3]

(3) Terrain loss, while increasing at higher frequencies is not significant until around 1 GHz.[4]

(4) Foliage loss, while increasing at higher frequencies is not significant until around 1 GHz.[5]

(5) Signal fading, while increasing at higher frequencies is only significant in the microwave range (>3GHz).[6]

Figure 1-4
Comparison of Signal Characteristics Across Public Safety Frequency Bands

[2] Bell Laboratories, Transmission Systems for Communications. Holmdel, NJ: Bell Telephone Laboratories, Incorporated, 1982: pp. 89-91.
[3] Hess, Garry C. Land-Mobile Radio System Engineering. Boston: Artech House, 1993: pp. 293.
[4] Bell Laboratories, Transmission Systems for Communications. Holmdel, NJ: Bell Telephone Laboratories, Incorporated, 1982: pp. 460-461.
[5] Hess, Garry C. Land-Mobile Radio System Engineering. Boston: Artech House, 1993: pp. 24.
[6] Bell Laboratories, Transmission Systems for Communications. Holmdel, NJ: Bell Telephone Laboratories, Incorporated, 1982: pp. 462-463.

- VHF and UHF systems experience better building penetration than do 800 MHz systems. The increased building penetration at lower frequencies allows public safety entities the ability to achieve in-building coverage with fewer repeater towers and less output power.

- Some metropolitan users achieved better coverage with new 800 MHz systems than with the older VHF systems. This improvement in coverage may be due in part to the addition of new tower sites throughout the metropolitan area.

- Because of added infrastructure and equipment costs at 800 MHz, the costs of VHF and UHF systems are generally less.

Technical Issues

- It is logical for system planners to consider the economic benefits of re-using existing infrastructure when considering migrating to 800 MHz. However, designing a new 800 MHz system based on old infrastructure generally leads to user dissatisfaction in terms of coverage (e.g., dead spots, dropouts). The additional infrastructure needed to implement the new system is costly, but necessary to ensure adequate coverage.

- Spectrum regulatory policy over the past 20 years has encouraged the use of more spectrally efficient technology. This trend is compelling vendors to take several actions:

  - Direct money for land mobile radio research and development into spectrally efficient technologies such as trunking technology and digital modulation schemes.

  - Direct money toward 800 MHz system development, to the exclusion of VHF and low-band UHF radio systems.

- The NPSPAC channels allow a 25 kHz channel bandwidth, which is adequate for data transmission. This issue is more fully discussed in Appendix B of the report (specifically, see page B-6, the paragraph labeled *Channeling Plan*). The FCC has adopted regulations that impose narrowband channel requirements on public safety radio equipment for bands below 512 MHz. These regulations, which apply only to new equipment, not legacy equipment, make data transmission more difficult at lower bands.

- The use of trunking technology has elicited mixed reviews regarding public safety communications. It is debatable whether the benefits provided through the use of trunking technology outweigh the costs associated with trunked systems and if trunked systems are needed by all public safety entities.

- Trunked systems allow improvement of system capacity. Trunking technology allows for the use of talkgroups as well as the efficient distribution of conversations over similar amounts of bandwidth.

- A common misconception associates increased capacity with the implementation of an 800 MHz system. In actuality, increased capacity is due to implementation of trunking technology or of additional channels.

- Capabilities associated with trunking (e.g., talkgroups, spectral efficiency) have helped to significantly improve intra-jurisdictional interoperability.

- Some systems engineers and administrators at both the state and county level are examining the possibility of migrating to trunked systems at lower bands as an alternative to implementing costly 800 MHz systems. Trunking in the public safety bands below 800 MHz is now allowed (FCC's Refarming Report and Order, 92-235, implemented in October 1997). Prior to this R&O, the lack of FCC provisions to develop trunking technology for bands below 512 MHz impeded the public safety's ability to improve communications systems with existing spectrum allocations.

- Concerns regarding the "push-to-talk" delay associated with establishing communications on a trunked system are often cited as a pitfall to the technology. This delay is minimal, on the order of hundreds of milliseconds, and can be compensated for with proper user training and education.

- Many small public safety entities (e.g., those that support rural, small counties) do not necessarily have the number of channels, the complex missions, or the system capacity problems to necessitate use of a trunked system.

- The lack of a trunking standard, which would allow for open architectures in radio systems, has led to the development of incompatible systems built by different vendors. The proliferation of these incompatible systems has impeded the improvement of inter-jurisdictional interoperability.

Operational Issues

- Many states, counties, and municipalities are replacing aging public safety radio systems with new systems operating in the 800 MHz band.

  - Channel congestion in the lower bands coupled with the availability of 800 MHz channels dedicated to public safety is prompting some level of migration by local and state entities to the 800 MHz band.

- Public safety agencies are currently operating on islands of spectrum that range from 30 MHz to 869 MHz. Due to the wide range of frequencies, it is difficult (but not impossible) to achieve, multi-discipline, multi-jurisdictional interoperable communications. The move to 800 MHz has both improved and hampered interoperability for some public safety agencies.

- Improvements in intra-jurisdictional interoperability at 800 MHz can be attributed to the use of trunked radio systems and more specifically to the use of talkgroups. The use of talkgroups provides public safety agencies with the capacity to establish interoperable communications on an as needed basis.

- Inter-jurisdictional interoperability has been hampered in some instances because many entities chose not to migrate to the 800 MHz. Without the use of a cross patching scheme or radio swapping, agencies operating in different frequency bands lose effective means of interoperable communications.

- The NPSPAC mutual aid channels have not improved interoperability among local, state, and federal public safety agencies on any broad scale.

  - A majority of public safety entities, especially federal agencies, operate in the lower frequency bands and are unable to easily or routinely communicate on the NPSPAC mutual aid channels.

  - Federal agencies were excluded from the NPSPAC planning and management processes and are not allowed to obtain licenses on 800 MHz frequencies to interoperate with other public safety entities.

  - These mutual aid channels that can provide the bridge between local, state, and federal governments go largely unused due to a lack of a common understanding of how to use these channels.

  - These mutual aid channels are sometimes not implemented because the costs of installing additional infrastructure to implement the channels is over and above the cost of installing a system that meets their requirements.

- Coverage areas are easier to identify with newer technology (800 MHz systems), because the portable and mobile radios indicate "in service" or "out of range," similar to commercial cellular and Personal Communications System (PCS) phones. Since no such indication was provided with previous radios, system users were unaware of exactly how large of a coverage area they were experiencing with these lower frequency systems.

- Planners who incorporated robust criteria within their Requests for Proposal (RFP) generally experienced greater critical in-building coverage and fewer overall coverage difficulties with their 800 MHz system.

- The 800 MHz radio systems are state of the art technology. As with any new technology there is an inherent transitional "learning curve."

  - User education and training for the new radio systems are critical components to a successful transition to, and implementation of, an 800 MHz system.

- Operationally, the new 800 MHz systems are more reliable than their predecessor systems. The reliability of the 800 MHz systems may be attributed to the technical capabilities and better planning and design associated with these systems.

  – Trunking technology permits a dramatic increase in capacity than previously experienced with older systems. This increase in capacity allows users to communicate on open channels and prevents overcrowding and overloading of systems.

  – The new 800 MHz systems represent a dramatic upgrade for many agencies whose previous radio systems were years past their original planned replacement age.

  – This perception of greater reliability may be skewed; users are comparing new 800 MHz technology to outdated and exhausted VHF or low-band UHF technology.